Robust Network Design

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SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT AND THE CIVIL AND ENVIRONMENTAL ENGINEERING DEPARTMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREES OF

MASTER OF BUSINESS ADMINISTRATION
AND
MASTER OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING

IN CONJUCTION WITH THE LEADERS FOR GLOBAL OPERATIONS PROGRAM AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2015

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Submitted to MIT Sloan School of Management
on May 8, 2015 in Partial Fulfillment of the
requirements for the Degree of Master of Business Administration
and Master of Science in Civil and Environmental Engineering

ABSTRACT

As an equipment manufacturer for the mining and construction industries, Caterpillar's business is heavily impacted by the cyclicality of these two industries. To be competitive in the market while investing prudently to ensure shareholders' value, Caterpillar needs to make capacity decisions with peaks and troughs of the cycles in mind. Through the peaks and troughs of business cycles, the perceptions change from not enough capacity to under-utilization of asset constrained capacity respectively. The purpose of this thesis is to establish a framework that enhances robustness in investment decision-making within the 2-6 year capacity planning horizon. This entails the ability to balance risk and return for the company and account for the cyclical nature of business and other strategic considerations. The project also aims to enhance consistency across stakeholders and introduce an aggregate risk perspective under corporate capital constraint.

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ACKNOWLEDGEMENT

I would like to thank Caterpillar Inc. for providing me the opportunity to intern at the company. Special thanks to my internship supervisor and project sponsor, Gregory Matson, who has guided and supported me throughout, from helping me make connections with stakeholders to discussing with me the content of the research; to Gary Decker, whose generosity with his time and resources was indispensable for the advancement and completion of my project; to Alagesan Thasari, whose immense help was always just a phone call away even though he was away in the UK.

I would also like to recognize the many Caterpillar colleagues who has given me a lot of inspirations, information and encouragement along the way: Petr Michlik, Eric Rohrbaugh, Lois Porzio, Nishant Bhatt, Scott Longhurst, Ge Zhou, Hadyn Frost, Jim Quigg and Chuck Neumann. I would also like to thank Linda Lundquist, and LGO alumni Denise Johnson and Glenn Bergevin, whose support made my transition from school in Cambridge to working at Caterpillar and in Peoria a smooth ride.

I would like to thank my thesis advisors, Chris Caplice and Saurabh Amin. They have both been extremely generous with their guidance and support, and have given me invaluable advice as my research developed and the thesis took shape. Also a big thanks to the LGO program who has been wonderful help from "home" while I was away.

Further, I would like to thank my friends in Peoria who made my first experience in the Midwest such a joy – my Peoria Grandma Lucy Dorethy, Abinayaa Panneerchavem, Meiosha and Tim Zobac, Tina and Ben Hoerr , Grace Wen, Shamier Johnson, Catherine Wolter and Rachel Hensold. Because of their generous inclusion into the inner circle I have managed to make myself *quite* busy in a city otherwise less eventful than Cambridge.

Finally, I would like to thank my family back in Hong Kong, whose never-ending support since I started applying for the LGO has been a constant source of peace and affirmation that there is no mountain high enough with you all as my backers. You are the best gift I have received from God, and while I did not think I could be loved more, the LGO experience has given me a yet deeper understanding of how much you mean to me. Thank you, and thank God.

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Table of Contents

FIGURES

TABLES

NOTATIONS

b - a constant in the logarithmic best-fit

CF_t – cash flow in year t for financial assessment

i – year when forecasting is conducted

k – discount rate applied in financial assessment

L_i _ N-year average level

N - the number of years in consideration for the average

R_i . N-year average trend

s - time in year representing the forecasted period (EPP) carried out at year *i*

t – time in year representing the backward looking period for determining level and trend

U – parameter for assessing error under Theil's U-statistics

Y_s - actual sales of year s

Y'_s – forecasted sales of year s

Y_t - actual sales of year t

Y'_t – forecasted sales of year t

WL_t – weight applied to average level across t years

WT_t – weight applied to average trend across t years

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1 Introduction

1.1 Project Motivation

As an equipment manufacturer for the mining, construction, energy, and transportation industries, Caterpillar's business is heavily impacted by the cyclicality of the markets. To be competitive while investing prudently to ensure shareholders' value, Caterpillar needs to make capacity decisions with peaks and troughs of the business cycles in mind.

In the history of Caterpillar, there have been times when there was demand capacity constraint (e.g. in year 2008 revenue increased by 14% but profit was up only 0.45%), but also times when facilities are over-capacitized (e.g. 2013-2014 due to the slowdown in mining). Therefore, there is strong motivation in establishing a decision-making framework for investment that would mitigate the impact of such fluctuations. There is also the important aspect of aligning thinking across the company so that people feel empowered to make decisions and are rewarded accordingly with respect to the goals of the company.

1.2 Problem Statement

The goal of this project is to establish a decision-making framework that facilitates investment decisions for capacity changes during the 2-6 year planning horizon. The framework will advise on a strategic plan that helps generate optimal financial returns for the company, accounting for the cyclical nature of business and supply chain risks. It will be guided by the objectives for the 0-2 year Sales and Operations Planning (S&OP), and the 7 to 10+ year Global Production Network Planning (GPNP). The project also aims to enhance consensus and uniformity across stakeholder groups in the capacity decision making process.

1.3 Thesis Overview

This thesis is divided into seven parts, each addressing an area of the research that is carried out. Chapter 1 (this chapter) sets the stage for the research and explains the reason for such a project; Chapter 2 gives a background on the organization of Caterpillar and its modus operandi pertaining to capacity planning; Chapter 3 is the Literature Review conducted around topics that are important to the capacity planning process, which provides support to all the internal information collected and helps shapes the final proposed framework; Chapter 4 defines the methodology for building the framework, the directions that have been explored, people engaged and sources of information looked at; Chapter 5 defines the current state of the company in relation to capacity planning and discusses issues along the process where desire for further enhancement would be benefit for optimizing company performance and enabling collaboration across groups; Chapter 6 discusses the proposed decision-making framework which is the outcome of all the previous research, including the changes that it is introducing and the analysis behind supporting it.

2 Project Background

2.1 Caterpillar Inc.

Founded in1925, Caterpillar Inc. is a multi-national, world-leading manufacturer of mining and construction equipment, diesel and natural gas engines, industrial gas turbines, and diesel-electric locomotives. In addition to equipment sales, aftermarket parts and service revenue is also a key component of the company's business. It enables the company to ride through cycles of the industry by "binding customers to the firm, preparing them for the eventual sale of new machines and providing revenue when sales of new machines decline" [1].

To support the size of such a business, the supply chain at Caterpillar comprises over 28,000 suppliers, located in 90 countries. Having sustained its business through the peaks and troughs for almost 100 years, the company has grown to an annual sales and revenue of $55 billion in 2014, employing over 110,000people, and operating in over 180 countries through its renowned dealer network with over 60% of sales and revenue from outside the United States. [2]

This global footprint has vastly expanded the market for Caterpillar in selling its products, and also necessarily means competition from not only global brands but also local brands especially in emerging markets. Additionally, the mining and construction industries in which Caterpillar has significant operation are also highly cyclical and unpredictable. The two factors together pose the challenge of planning the right manufacturing capacity to meet the level of demand and maintain market leadership.

2.2 Caterpillar Production System (CPS)

The Caterpillar Production System organization was formed in 2005, and serves as an internal consultant to the company with the goal of helping the enterprise set the 'gold standard' for our industry as we produce the highest quality products as efficiently and safely as possible" [3].

The nature of the work is highly relevant to the operations of each product group and thus many members of the team have had that experience of actually working on at a product level; on the other hand, the mission of the team to set the 'gold standard' also mandates that an analytical and tested approach be adopted in introducing a new system of works. There is thus a significant element of quantitative reasoning in the work at CPS; a third and important aspect of CPS work is change management, as buy-in from all stakeholders is necessary for any new system to be adopted and used.

Capacity planning is a function that rests within the Product Source Planning sub-team of CPS. The responsibility of the team is to devise tools for capacity determination that can be applicable for different product groups across different seasonality and cycles. As a result, while the project is supervised by the Supply Chain sub-team, there is close collaboration with the Product Source Planning, especially toward the second half of the project where next-step implementation is being considered.

2.3 Network Planning Horizons

The primary goal of network planning is to match supply with demand, and Caterpillar treats it in three distinct planning horizons. Figure 2-1 shows the time line of these three horizons in Caterpillar.

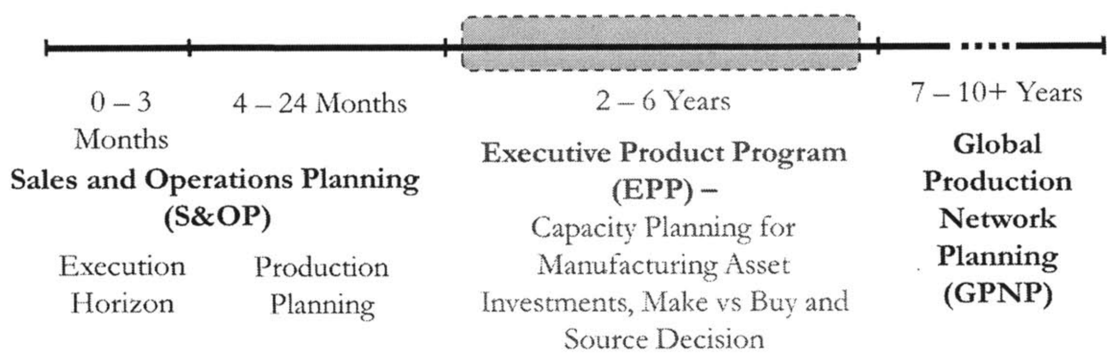

Figure 2-1 Execution and Planning Horizon at Caterpillar

1) Sales and Operations Planning (S&OP)

This is the 0-2 years production planning window, where production levels are determined for individual product model at different facilities and implemented on the shop floor based on near-term demand forecasting using the latest sales information. While it is the product groups that ultimately make this decision, a team of experts housed in CPS supports the process.

2) Executive Product Program (EPP) – capacity planning

This is the planning and decision making process for the 2-6 year timeframe from now where a target capacity is required to meet demand projections, and is the focus of the project. It is a very strategic process on different levels:

1) Near term – the decision to increase capacity requires capital, which can potentially strain cash flow for the company;

2) Long term – the decision to increase capacity would enable growth, and thus position the company at a competitive spot versus other market players

3) Throughout the lifetime of the investment – the decision to increase capacity has profit and loss impact to the company on annual basis, as well as daily operational implications

4) Requires collaboration across the company – because of the complexity of the decision, strong management required in integrating different teams and making decision through a process and based on assumptions that are consistent across the board.

The EPP process is understandably the most challenging of the three, given the magnitude to decision to be made and the need for actual action to be taken today (dollars invested), under a forecast that is largely uncertain. While CPS has an EPP team that offers daily support to the process, there is also another team (the Product Source Planning team) that looks at how the process could be further enhanced. Nevertheless, "The Worldwide Product Manager is the focal point of the capacity planning process for prime products. As the entrepreneurial owner of the product, the WWPM drives the business decision for the enterprise capacity plan of the product line. The capacity "gamble" is one of the principle responsibilities of the WWPM" [4].

3) Global Network Production Planning (GPNP)

This process establishes the long-term vision of the company in terms of its manufacturing footprint. It has two key components – what is the optimal split between make and buy (a sourcing decision) and what is the best place/size for manufacturing. It is an exercise based on both expectation on global environment and industry development (which is going to be largely inaccurate), but also the strategy and vision of the company regarding where it wants to be in this market. Either factor can change (for the latter – change in management would likely solicit it), but while it works on the least information, it also has relatively smaller implication compared to the S&OP and EPP processes, with limited actions taken today. The planning for GPNP is done centrally and led by a team in CPS.

3 Literature Review

3.1 Demand forecasting

Matching demand with supply is a challenging task for any industry. For some industries it is possible to structure the supply chain such that rapid reaction can be effected to cope with changing demand signals, e.g. fashion retail [5]. For other industries where lead time to production is necessarily long, such as Caterpillar, managing the business cycles to come up with an accurate demand forecast gives a company a strong competitive advantage.

Traditional approaches using historical data to establish future trends are well-used across different industries, including exponential smoothing using moving averages or Holt's linears method, regression, and autoregressive integrated moving average (ARIMA). [6]

In order to tackle demand signal fluctuations, researchers have examined different methods to adapt the forecast with increased agility. Graves et al. [7] proposed a two-stage forecast evolution process to smooth production.

Where capacity planning is concerned, the seasonality within a year is relatively less important as it can be balanced out with inventory management. On the other hand, having a combined view of short-term and long-term may provide perspective to what extent a sudden demand surge can be coped with, and how much capacity needs to be made flexible when demand drops. To lend stability in the forecast while retaining characteristics of seasonality, Kourentzes et al. [8] proposed the concept of temporal aggregate and forecasting, whereby the original data is transformed to lower and higher frequency such that at low aggregation period components like seasonality would be retained, while at high aggregation levels and trends are more apparent. This is potentially more appropriate for capacity planning given the stability of trends is needed for making actual asset investment decisions due to its long-term nature.

3.2 Capital Investment Evaluation Methods

Traditional capital investment decisions are largely based on the return that could be expected out of the project – Shapiro [9] proposed that approval of an investment project should be based on its positive net present value (NPV). According to Alkaraan and Northcott [10], other measures are also typically used, including the use of return relative to the amount of investment (Internal Rate of Return or Profitability Rate), return made with reference to the time needed to acquire it (payback), and return in comparison to the risk it is subject to (risk-adjusted IRR or payback). All these different measures have their merits and deficiencies. Table 3-1 summarizes the common methods and their major pros and cons [11, 12, 13].

Table 3-1 Comparison of Capital Budgeting Techniques

	Net Present Value (NPV)	Internal Rate of Return (IRR)	Payback Period	Profitability Index (PI)
Definition	Present value of the cash flows based on opportunity cost of capital and value generated by project	Rate that makes the present value of future cash flows equal to initial cost	Time before initial investment of the project recovered	Ratio between the discounted cash inflow to the initial cash outflow
Pros	Direct measure of dollar benefit and easy to understand	Allow explicit hurdle rate to be set	Easy to understand	Allow explicit hurdle rate and ranking of projects
	Incorporates concept of time value of money	Provides indication on margin and capital efficiency	Less affected by uncertainty in long-term cash flow	Reflects on capital efficiency and value added to company
	Incorporates risk of future cash flow via use of discount rate	Works as a ratio and is less affected by demand shock	Biased toward liquidity	Works as a ratio and is less affected by demand shock
Cons	Requires selection of a discount rate	May not give correct decision with non-conventional cash flow or mutually exclusive projects	Ignores time value of money and cash flow beyond payback period	May not give correct decision when evaluating mutually exclusive projects
	Does not reflect on capital efficiency	Ignores economies of scale and dollar value of project	Lack of indication that the project adds value to company	Ignores economies of scale and dollar value of project

Taking the idea from option pricing in the financial world, Myers [14] proposed the methodology of "real option" for the investment in multi-stage non-financial investment such as manufacturing plant expansion. The idea is that the uncertainty can be reduced as more information comes in with time. It is still based on NPV or IRR calculations, but provides the option to defer, abort or expand in the course of the project, thereby increasing the expected return of an investment. Such an analysis is seen as promising for use in the pharmaceutical industries where projects often receive little or no attention because of the risk involved, provided the investment is of a multi-stage nature where there is the opportunity for continual assessment of the situation [15]. For some other industries, implementation of this method has met with certain difficulty, mainly the hurdle to obtain management buy-in given its complexity. Ragozzino [16] studied a sample of 24,000 global transactions over 16 years and concluded that multi-staging projects and thus enabling real-option decision making is not always possible.

These hard measures of return provide a view to how an investment would impact the financial situation of a company, and is often the main, if not sole, consideration for financial investments. For industries, investment in capacity can often have a softer aspect of consideration which impact the strategic positioning of the company. Berkovitch and Israel [17] even argued that the NPV criterion alone (or any financial technique by itself) will not be conducive to best interest of the company because the agency problem would induce managers to manipulate the project selection process by presenting projects such that managerial utility is maximized.

Kaya [18] researched the strategic motives of Turkish manufacturing firms in investing abroad, and concluded that market potential of host country / region was often the key reason for such investment, while lower cost of inputs and access to capital or know-how are relatively less importance. Companies also build capacity sometimes as a response to potential threat of market entry. Oster & Strong [19] observed this phenomenon in the airline industry where low-cost subsidiaries like Delta Express were launched to "target the threat of Southwest and other low-cost, low-fare airlines". Porter proposed several reasons for industries to build capacity:

To summarize from researches reviewed, investments could be made for the following strategic motives [18, 20, 21]:

- Market potential in country of investment
- Protection of market developed through trade
- Favorable relations with country of investment
- Quality of infrastructure in the country of investment
- Foreign government incentives for foreign investors
- Access to capital

- Access to know how and technology
- Preemption of new market entrants or other competitors
- Supply chain strategy – lead, lag or track
- Sustainability (mainly in the environmental and social sense)
- Strategic orientation of company and stage of manufacturing effectiveness
- Potential of a growing market / product
- Opportunity for workforce development

The actual strategic measures that are pertinent to a company would be those that are matching with its unique corporate strategies, and should be guided and reviewed by senior management.

3.3 Investment under Uncertainty

When investing under uncertainty, there are various metrics that one can use to measure the degree of uncertainty and make a decision based on that. This section looks at a few common ones that are better understood and accepted.

1) Value at Risk (VaR)

Value-at-risk measures "the potential loss in value of a risky asset or portfolio over a defined period for a given confidence level" [22]. It was first used in the investment community to set capital requirements of financial service firms to potential losses that would be incurred. Since 1995, VAR has been mandated by various regulating authorities around the world to be used by financial institutions under their jurisdiction. [23]. In the last decade, VAR continued to build its audience with the financial community and beyond.

A main advantage of the VAR measure is that it provides a quantified measure of risk in terms of a specified level of value loss over a defined time horizon with a confidence interval, and a consistent treatment of risk across different activities. It addresses the consequence and likelihood aspects of risks which some other measures fail to address (e.g. sensitivity analysis). By expressing risk in dollar terms, VAR "makes possible direct comparisons of risk across different business lines and distinct financial products", and offers a view to the aggregate firm-wide exposure. [24]
The market has developed three main methods for measuring VAR:

- Variance-covariance method: mapping individual assets to normal distributions of standardized market instruments (and thus the underlying market risks) and assigning different weights. By developing variances and covariances of these instruments and applying different weights based on the assets in the portfolio, the aggregate VAR can be derived. Applied to a specific capital project, different risk factors / inputs would replace the assets and their importance the weights, while variance / covariance applied would be derived from historical movements of such factors albeit limited by the assumption of normality.
- Hypothetical portfolio method: VAR in this case is estimated by creating a hypothetical time series of returns of a portfolio using actual historical values and variability observed. This method is more difficult to replicate with capital projects given the unique nature of each compared to past projects, and is limited by the fact that the past is not necessarily indicative of the future;
- Monte-Carlo Simulations – This method begins with identifying risk factors (or input factors) to the return outcome, assigning probability distributions (assumed or based on historical)for each factor and specifying how they move together, and repeating a series of simulation runs to generate a distribution of portfolio values. While Monte Carlo simulations are often touted as more sophisticated than historical simulations, it is also only as good as the probability distribution assigned to the inputs and is not bound by the normality assumption.

VAR is often criticized for its inability to address the risk of extreme events that occur in the tails of distributions, and its ignorance of upside returns. Understandably no one metric could serve as a sole measure of risk, and ultimately how companies should measure and manage risks depend on why they manage risk. Researchers have proposed several enhancements to make the VAR measure more valid: conducting stress test in conjunction with VAR, deploying good management with well-developed organization infrastructure and IT system to manage the dynamic process of risk taking and control, and enhancing the VAR perspective to an NPV-at-Risk one to combine the weighted average cost of capital and dual risk-return methods or a cashflow-at-risk perspective to take care of concerns over the flow of funds in a company [23, 24, 25].

While VAR does not consider extreme events nor upside risk, no form of risk measurement can embrace all aspects. The ultimate adoption of a measure should be one that fits the company culture and operation – "why a company manages risk will dictate how they should manage it" [24].

2) Standard Deviation of Return

A more traditional way to look at risk is the standard deviation of return – either that of NPV or IRR. This gives a sense of the spread that can be expected of the average return, and thus the range of NPV or IRR within a certain confidence level. This method appeals to those who prefer a more academic and mathematical because it follows the first principles of statistics. From a practical perspective, business managers can find it difficult to react to a percentage or a ratio because it is less intuitive and harder to set a cut-off for decision-making.

3) Probability of Zero NPV

An even more straightforward measure is the probability of zero NPV, which some teams internal to Caterpillar are pushing for given its simplicity. It is based on the same Monte Carlo simulation that would be needed to generate the VAR, and informs the probability that a project has zero or negative NPV based on the distribution.

The challenge with using this measure is that there is no defined way to determine the cut-off probability (except analysis on historical data), which possibly render the decision quite arbitrary. A second disadvantage is that this measure is not indicative of other aspects of the project such as the size of project, and like VAR it does not account for extreme events nor upside risk.

3.4 Summary

The literature review suggests that there are various forms and means one can adopt to forecast demand, assess financial viability of projects and account for uncertainty. From an academic standpoint, some methods are more intricate than others and cater for more complex scenarios (e.g. real option); from a practical standpoint to be applied in a corporate context, what is intuitive and simpler may have found more success in being readily adopted (e.g. the NPV or VaR method). The different possibilities presented in this chapter, combined with the unique situation at Caterpillar described in Chapters 4 and 5, give rise to the recommendations made in Chapter 6.

4 Methodology

To determine a reasonable direction for enhancing the current capacity determination system, it important to study the current process first and identify the gaps. On the internal side, process flows were mapped out and stakeholders involved in the process were involved to share their views, experience and feedback on the current system. On the external side, discussions were held with companies operating in industries similar to Caterpillar who are facing similar capacity issues; this helped generate ideas for improvement and benchmarking, as well as understanding of potential problems associated with different capacity build strategy. This information, together with the Literature Review, is used to determine the right model to adopt with calibration and validation by existing data. This chapter summarizes findings from those individual interviews, as well as the approach thus developed to address pain points identified.

4.1 Interview with Internal Stakeholders

Capacity determination is an important subject within Caterpillar that concerns a range of stakeholders, and decisions made impact company financial and operational performance in significant ways as well as the metrics of individuals and business units. To understand pain points of the current system and establish a direction for enhancement, interviews were conducted with stakeholders involved in the whole process.

i) Product Managers

They are the ultimate user of the process and are solely responsible for the performance of their products. They generally seem to appreciate the need for more discipline for the capacity determination as well as transparency in the coordination process. As such they (as represented by their staff who are responsible for the capacity planning process) are willing to attempt a new way of work that would help tame the unpredictability of outcome they currently suffer from and improve their performance metrics.

In particular, under the Product Managers there is a team of people who are very experienced with product and market performance, have all the necessary data in their hands. They are potentially capable of establishing a model that would work for them except the EPP process has to be completed within limited timeframe. The challenge is therefore to create a robust system simple and direct enough that would be appealing from the accuracy as well as efficiency perspective without requiring very specific technical expertise to implement.

Also, another consideration is the performance metrics applied on product managers. Most product managers are of 5-year tenure. Metrics such as single-year RoA (previously used) or single-year OPACC (currently used) could produce investment decisions good for the short-term for not necessarily for the long-run. Meanwhile, the changing metrics and systems could introduce instability and confusion into their teams and operations on the shop floor.

For the purpose of this project I have interviewed and worked closely with personnel from five different product groups.

ii) The Forecasting Team – Business Economics, Machine Forecasters and Marketing Consultants

The Forecasting team is the originating point of the entire capacity determination exercise, and are critical to setting the right direction for the whole company. Even though product groups perceive the LTF to be historically overly optimistic, from forecasting perspective variability is inevitable and anything within the range is acceptable. The imperative that the Forecasting team maintains is that they follow a system that is bottom-up and technically sound; the rest of it is really unpredictability.

Partially because of this, the forecasting team (specifically the Business Economics team) has moved from making predictions with cycles to just providing a trend line, with a band that indicates the range of variability within a confidence interval. This is to not set the wrong expectation in product groups that a particular year is certain to be a peak / trough year.

Tasked with the impossible mission to predict the future, the Forecasting team also recognizes that there is always a better way of forecasting, and are working with a team to develop higher resolution of the probability distribution of demand. This is also something a product group has mentioned as useful – that it would be desirable to narrow the band for nearer term and acceptable to have widening range of variability as the year progresses.

iii) Corporate Investment Governance

The Corporate Investment Governance team has significant influence on capacity determination as they are the owner of the investment approval process, and gatekeeper for the senior management. Being in such a position, they have the authority to also mandate that a certain process has to be adopted before a project can be approved. As such, getting their buy-in in any sort of framework is critical, and I have worked closely alongside this team to understand the issues at hand and what kind of a solution would appeal to users.

Having reviewed all the Green Book Proposals and their subsequent Post-Investment Audits, the Corporate Investment Governance Manager also believed there remained improvement to be desired in the process, especially in removing the emotion that is often attached to decisions being made. A tool that would introduce more objectivity in thinking while remaining not too complicated and refined would be a good direction to pursue.

It was also cautioned that while continuous improvement is necessary, it is also important that changes do not happen too often and too quickly. Because of the complexity of the capacity planning process and number of people involved, any new measures would require adaptation by many; factoring in the natural turnover of teams, management may find the need for constant staff training an impediment to their effective working.

iv) EPP process owners

The EPP process owners have a wealth of knowledge about the entire capacity determination process as well as the challenges product groups face from year to year. They understand the current dilemma in demand fluctuations and complexity in capacity investment across different business units. Being in the observer seat, they have a more objective sense of what needs to be done – and a key point is that product groups should not assume all growth, all sales and all volume are good. There are more expensive capacity to build, more expensive customers to serve, and lower margin products to sell. The imperative is to conduct analysis that offer the right level of granularity in data and thus facilitate more precise decision making.

On the one hand, they feel a responsibility toward instituting a robust system that enables success for product groups in planning their capacity. To that end they have published a white paper to delineate the process, the considerations to be accounted for, and the pitfalls to avoid. On the other hand, responsible only for governing the process, they also have limited influence in data analysis and decision making.

v) Product Source Planning (PSP)

This is the team within the Caterpillar Production System organization that is responsible for instituting and facilitating a system for capacity planning. While technically under the same umbrella as the EPP owner, they have an overall responsibility to design and institute systems within the company to plan for the longer term and undertake more strategic studies. The capacity determination problem of this project is actually under the purview of this team. It is therefore important to engage with their team throughout the process, understanding the work they do now, and to identify and address gaps not being worked on.

Looking at previous years of capacity build record and sales performance, the general sentiment in PSP is that recent assumptions of capacity needs were too optimistic, and build was undertaken way before there was demand signal. In some cases it is uncertain if demand would ever catch up. As such, PSP is also looking at ways to improve the system and introduce more precision into its analysis and discipline in the process. The problem they face is to engage stakeholders and obtain buy-in. In particular, these include Corporate Investment Governance to endorse any proposed system or framework, and product groups who would be doing the actual work.

4.2 Survey of External companies in investment assessment framework

The need to invest under uncertainty is common across different industries, and each company has its own perspective to how risk is taken into account. I have approached three different companies in a similar heavy manufacturing industry to understand how they account for risks and make investment decisions that involve significant long-term assets..

A major Japanese Automotive Manufacturer

In terms of investment approach, the automotive manufacturer uses Return on Investment (ROI) as the primary metric for decision making, with a pre-determined hurdle rate. Duration for assessment depends very much on the nature of the project - e.g. for infrastructure supporting manufacturing, the building itself is not necessarily model-life based; the equipment on the other hand will be assessed based on how many model lives it can support. In that sense, flexibility should improve value of the project, although ensuring success of the initial product launch would be the main driver. Payback period is not typically used for the assessment, although a rule-of-thumb is that it would be around half the product life.

In assessing the risks and uncertainty in investment, the automotive manufacturer examines historical trends over a given interval as a means of defining probability, interval, and impact of that risk going forward The purpose is to understand the situation under spike, decline and average scenarios, to understand the actual costs associated with each, and to plan for the norm and develop contingencies. A self-contained mathematical model as there are myriad factors to be accounted for, but a key consideration would be unbreakable processes that are designed for success in all scenarios. As an example, demand risks should be managed by pre-designed measure of processes to contain unit cost within a certain range. Such measure should be irrespective of spikes/declines, and whoever is managing the process.

A large U.S. Defense Contractor

Capacity determination begins with the finance team providing a projection on upcoming contracts, the relevant revenue / costs and thus the headcount and footprint required. Given the nature of the defense business is high-mix low-volume, flexibility is gained from adjusting the number of shifts on the people side, and re-purposing the shopfloor from manufacturing one product to another. The latter is made possible by not building in too much automation or monuments in the first place when planning the facility. If long-term projection of a production is still optimistic, divestment / consolidation decisions are generally not made. Similarly on the supply base side, the make/buy decision is an optimization between flexibility and cost.

From an investment assessment perspective, the general metrics used are IRR, payback period, 10-year NPV (for some projects it may be 20 years depending on nature of asset acquired). These metrics serve as "disqualifiers", while qualified projects are further scrutinized and weighed based on other factors such as upfront capital requirement, affordability etc.

From a risk perspective, examples can be drawn from the implementation of existing build programs. The risk-opportunity for different scenarios are analyzed based on their financial impact and the corresponding probabilities.

A major U.S. Automotive Manufacturer

Capacity planning is performed centrally for all global businesses and driven by individual product programs. The manufacturing planning team leads the effort in collaboration with general manager for each of the four regions supported by regional economists in determining how strong the sales volume by customer segment would be compared to current products and competitor performance.

While the business is subject to cycles, the company does not plan for wide swings of demand but more for the long-term trend with a consciousness to not over-plan capacity (the philosophy is to plan for being one unit short). Re-usability of assets is generally low because of model specificities, while shared platform is a challenge because of different market requirements. There is also limited alternative for sourcing unique parts – additional suppliers will need to be tooled up to cope with demand peaks.

The decision-making framework is based on both on financial and strategic criteria. The first step is typically to accommodate the need in existing facility, and if new ones are needed, build close to where the consumption is. Discounted Cash Flow is conducted for alternatives with an aim to maximize Return on Invested Capital (ROIC). Risk is assessed using sensitivity analysis, e.g. looking at the likelihood of events such as history of deficit or currency fluctuations in countries like Argentina, but can also be a subjective evaluation (e.g. labor risk, event risk, political risk etc.) For emerging market, the need to build is almost natural because of the demand that is there.

4.3 Framework construction and model building

The insights shared in internal discussions and external interviews have provided a general direction of what this project could potentially enhance. The literature review and textbook reference, on the other hand, formed the foundation for applying specific methodology to derive a model. During the process of framework and model development, the stakeholders interviewed continued to be involved in ensuring the availability of the right data, the reasonableness of the approach, and the usability of analysis undertaken in terms of ease for product groups or relevant business unit / personnel to take over.

This is an iterative process, where the first attempt to draw up the whole framework and secure stakeholder buy-in through elaborating on the concept behind and problem it targeted was crucial. After crossing the initial hurdle, it became easier to obtain data from relevant parties to validate and refine the model that was created.

5 Current State of Capacity Planning

The 2-6 year network planning at Caterpillar comprises two main decision making points – capacity determination under the Executive Product Program (EPP), and business proposal approval under the "Green Book" process. Figure 5-1 Process Map of 2-to-6-year Network Planning shows the mapping of the entire process, including the main parties involved in each step.

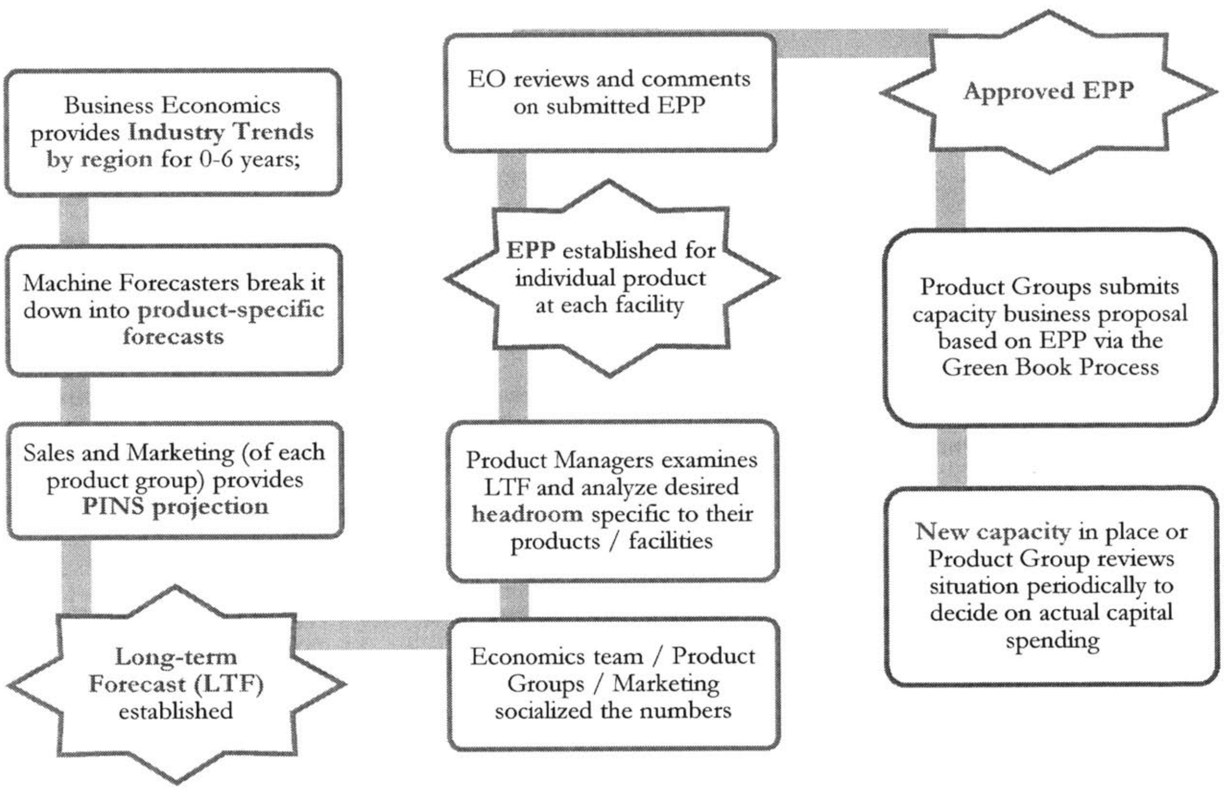

Figure 5-1 Process Map of 2-to-6-year Network Planning

5.1 Demand forecasting

Demand for a piece of Caterpillar equipment is broken down into two parts – an industry forecast multiplied by Percentage of Industry Sales, also known as PINS, that Caterpillar has. Such a forecast is the concerted effort of a team comprising Business Economics, machine forecasters and market consultants.

The process begins with Business Economists providing an industry forecast by product family by region. There are two contributing factors to industry demand - fleet growth and replacement of old machines.

Fleet growth is a combination of economic factors such as GDP, inflation, commodity prices, energy demand forecast (especially for mining equipment), as well as activities like housing starts and infrastructure development (especially for construction equipment). These economic indicators translate into the amount of work needed to be completed, the investment that goes into completing such work, and the value of equipment involved. Using the estimates thus produced, Machine Forecasters further derive the industry demand by product, based largely upon historical ratios. Qualitative reasons for adjustment to the split such as migration from one product to another, technology advancement or obsolescence are also taken into account.

Next a Decay curve is used to determine how the machine population productivity is reduced. This can mean retirement, needing to be replaced, or wear reducing capability, etc. Replacement of old equipment is derived from existing machine population and its age profile based on shipping data. Dividing that by the average lifetime of a piece of equipment one can derive what proportion of the equipment out in the market needs to be replaced in a certain year. There is also an assumption productivity of replacement machines, typically higher, and the possible substitution by other machines or techniques. This, combined with the demand of new equipment, generates the Industry Long-term Forecast (Industry LTF) of equipment.

Using that product-specific industry LTF a Percentage of Industry Sales (PINS) is then applied to estimate the units of Caterpillar sales that can be expected under such an industry environment. The figure is provided by a team of marketing consultants who are conversant with the particular product they are responsible for, the market the equipment competes in, and the past and planned actions taken both by Caterpillar and its competitors to boost market share. Dynamics that go into the determination of this figure include internal considerations such as new technology / feature introduction, commitment to growth (which may affect pricing), and model changes, but also external factors such as competitive actions and feedback from field teams. The final PINS forecast is determined both through discussion with the Business Economics team and product groups. It is worth noting that the PINS is to some extent both an estimate but also an aspiration – what product managers feel compelled to achieve given the imperative for growth.

While the PINS is determined at an aggregate level by product, it is sometimes further broken down into a by-model Caterpillar sales prediction by Machine Forecasters to facilitate capacity planning decisions given different models may require different machines for manufacturing. This prediction of by-product or by-model Caterpillar equipment demand is referred to as the LTF (Caterpillar Units). The owner of this LTF (Caterpillar Units) is the Worldwide Product Manager, who has ultimate responsibility for the profit and loss of his or her product based on his decision on capacity build and production planning.

5.2 Key Findings from Demand Forecasting Process

In general, the LTF is understood to be an average trendline of a cyclical business, representing the 50th percentile of demand. Therefore it is expected that 50% of the time the actual demand will be above the LTF and 50% below, which is important to note as it necessarily implies there will be times of over-capacity and times of under-capacity depending on where the capacity is set yet, and the timing of such peaks and troughs is unpredictable.

From interviews with product groups, it is understood that the LTF is generally perceived to be positively biased – there is a general "optimism" that drives the forecast to be more than what it realistically has been in history. Analyzing LTF data and comparing it with actual sales, two phenomena are observed:

(1) A positive bias: As shown in Figure 5-2, the LTF is significantly higher than the average trend that is it intended to represent; applying a further headroom as product groups are expected to tends to exacerbate the over-estimation of the needed capacity;

(2) A "recency" bias: Also observable from Figure 5-3, the movement of LTF from year to year echoes well with the movement of the actual sale. The plot suggests a very strong positive correlation between the two - meaning if the projected sales is improved from last year, the entire LTF trend moves up, and vice versa. This is not in line with the original intent of the LTF where actual sales are expected to cycle about it.

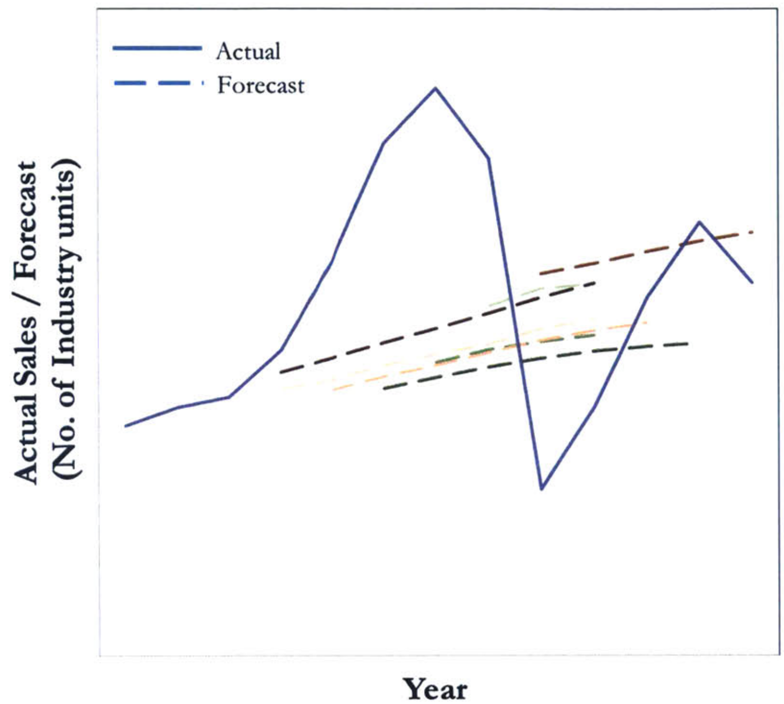

Figure 5-2 Comparison of Historical Actual Sales & Forecast (Industry)

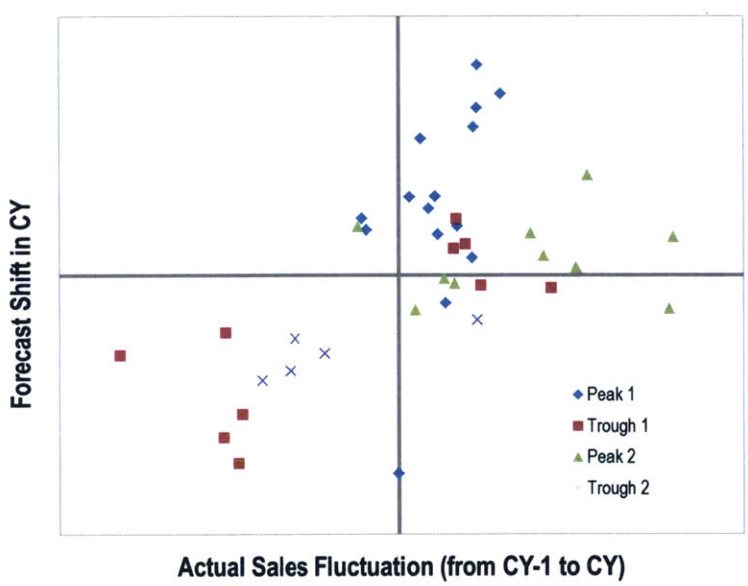

Figure 5-3 Forecast Shift vs Actual Sales Fluctuation (Product Group X)

As the LTF(Caterpillar sales) is calculated by the PINS, perception is that it is mainly the aspiration on PINS that drives such a phenomenon, while the industry forecast is generally realistic and robust. If one is to examine data on Caterpillar sales as well, one would note a similar phenomenon as that shown in Figures 5-2 and 5-3, indicating the same bias is observed.

It can therefore be argued that the challenge of forecasting is in both the industry forecast and PINS projection. In fact, PINS represents the performance of the company versus its competitors, and does not necessarily follow a cycle the way industry performance as a whole does. Therefore, taming the forecast involves a concerted effort from both the forecasting team and the product group to determine what is realistically achievable in the past and what the future portends.

5.3 Capacity Decision

Based on the demand forecast consensus, project groups apply a certain percentage buffer called "headroom" to establish the target capacity – which becomes their EPP inputs. In order to gain PINS and "be number one or number two in every market", Caterpillar adopts a "lead" approach in its capacity planning. General guidance allows for the capacity levels to be set at a fixed percentage above the LTF.

However, capacity at individual facility for specific products is governed by a host of other factors, such as enabling a balanced and stable production flow on the shop floor, cost of production. Coordination with suppliers and component plans is another significant, or even pivotal, factor. Since capacity needs from individual product groups is consolidated at the component level for manufacturing of common parts, sometimes product groups scale up or down their capacity plan depending on capital charge from component group in their corresponding capacity build. Add to that the skepticism that LTF is generally over-optimistic, the target headroom can range at the discretion of individual product groups. Therefore as much as there is a set of guidelines and processes for capacity determine, the ultimate decision is often a consensus after multiple discussions amongst stakeholders.

Before deciding on the target capacity to be put forward as a final EPP submission, project groups conduct their own "internal analysis" regarding the viability and risk of such a proposal based on lead time and capital requirement of the proposed capacity build provided by EPP owners. The final product of the capacity determination exercise is an executive summary of the time and resources for the capacity proposal, the consideration for the prime product itself, as well as the implications across component groups and upstream suppliers.

5.4 Key Findings from Capacity Decision Process

Where it comes to information aggregation, the current capacity determination process is systematic and uniform across product groups, but where criteria for decision is concerned, there is a general lack of standard and thus room for enhancing further discipline. One area is the prevalent mentality that beyond the 3-4 year window EPP numbers are of little significance. From interviews with stakeholders involved, the target capacity set for that period is often just a "placeholder" since product groups know that there is no actual action being taken. This reduces the seriousness of this exercise, and its ability to act as a medium to long-term plan that would position the product or the company for growth. In this connection, it is stated in the design of the EPP process that product groups are obligated to develop and obtain approval for Capacity Business Proposals (ie. green books) to fund the approved EPP. Given the commitment this represents and impact on other teams, adjustments to EPP estimates should be limited from a year on year basis.

Secondly, the extent of financial assessment and risk assessment during this EPP stage is also generally limited and not defined uniformly across groups. As mentioned above, product groups use capital and lead-time data provided by the EPP team to evaluate metrics such as Payback Period and Return on Sales and thus viability of the capacity build proposal.

Since the CEO introduced the key metric of Operating Profit after Capital Charge (OPACC) in 2010, product groups shifted to use that as the primary metric to determine whether a capacity project should be proceeded with. The definition of OPACC is the operating profit (revenue – COGS) minus 17% of the asset value used to generate the sales. This measure is effective in creating a focus on asset utilization and inventory management. Assets not well-utilized to generate corresponding return will be hit doubly hard (due to depreciation as well as capital charge) and clearly reflected in the OPACC performance.

While this measure is effective in driving capital efficiency, it does not improve from the previous metric of Return on Assets (RoA) in providing the long-term product growth perspective. Depending on the sentiments of the year, this will either drive over-aggressive capacity investments that are non-value accretive in the long run, or hold product managers back from investing when prices are low even though the demand has not come in yet. With an average of 5-year tenure for product managers, it is objectively reasonable (and have been confirmed anecdotally) that decisions could indeed be made based on short-term performance just to survive through the present challenge.

Another potential challenge is that product groups consider the time frame within the EPP stage to be very tight for multiple rounds of coordination. For a robust project perspective assessment such as Net Present Value, they may not have the resources and capacity to do so. A simplified tool that would help product groups look at long-term impact of capacity build plans would be desirable to complete the picture.

5.5 Capacity business proposal

Upon EPP approval, product groups would proceed to work on a detail business proposal for their capacity build project. This is called the "Green Book Proposal" at Caterpillar for legacy reason, and owner of the process is the Corporate Investment Governance team.

To build a robust case around a capacity build proposal, the product group has to conduct the following: NPV and IRR analysis of the project based on projected cash flows throughout the project duration (typically ten years). To deal with risks that are involved, there are three other analysis that product groups have to undertake:

(1) a sensitivity analysis around the variability that may be expected due to risks around the input data (e.g. price markdown due to over-capacity in the market, inability to gain PINS, industry volume fluctuation, etc.). This helps the management teams develop a perspective on how much the anticipated return of a project could vary

(2) a breakeven analysis that gives insight into the minimum annual volume required to make the project viable – comparing this with historical trough demand gives management a sense of whether the business case is realistically achievable from an intuitive sense

(3) a risk-adjusted NPV analysis that raises the hurdle rate to be used depending on the country of investment, nature of business arrangement, product of major market share, etc. This provides a more conservative sense of what the expected NPV would be.

Other factors to consider such as alignment with the GPNP view of global manufacturing footprint, supply chain's ability to cope with the expansion, other alternatives available and recovery plan in case of trough demands are also taken into consideration in a more qualitative sense.

5.6 Key Findings from Capacity Business Proposal

Understanding that capacity investment can be a risky thing, the Corporate Investment Governance team is always looking for more robust ways to look at investment options and assessment. This was why the breakeven analysis and risk-adjusted hurdle rate were introduced into the system and have been very useful in giving more definition to the risk involved in a project. However, these measures also do not point very explicitly to the "invest-ability" of a project, which means product groups and management ultimately have to decide relatively subjectively whether they want to take the risk.

Additionally, the sensitivity analysis provides a very helpful perspective on how the outcome of a project can develop if a particular assumption does not work out (magnitude of risk); Nonetheless it does not lend a view to how likely it is for that magnitude of risk to take place, nor does it consider multiple parameters varying to different degrees and the correlation between parameters.

Because there is no hard measure for comparison, and the fact that a project is submitted for the Green Book process signifies the product group has assessed the risks and is wanting to proceed, there is rarely any project that is denied. On the other hand, this phenomenon can also be interpreted as product groups being overly conservative about putting forward capacity build proposals because of the negative OPACC impact that it would have in years when demand plummets. The consideration that should be given is that in a cycle business the occurrence of such outcome in singular years may almost be inevitable. Having a detailed trough management contingency plan, taking a long term view and giving time for a project to mature and reward product groups for the right measures (not only results in one year but also on a long-term basis) are elements that seem to have less of an emphasis in the current modus operandi.

6 Proposed Future State of Capacity Planning

Having reviewed the current state of capacity planning through stakeholder interviews and data analysis, I have identified three main areas where enhancements to the current system could be desirable to tackle the challenge that product groups are facing today:

- Demand forecasting – an augmented demand forecasting framework utilizing the existing Long-term forecast, as well as a time series analysis based on historical data to tame the overly optimistic aspirations represented by the LTF
- Financial assessment of project risk and return - using Monte-Carlo simulation that allows variability across industry trends, market share, prices and margins to be applied, the outcome captures the average and spread in the return of a project to reflect not only the benefits but also the value-at-risk of a project; this aims to provide a more complete view of risk and return, introducing more discipline but also a long-term view in capacity investment for product groups
- Holistic investment decision making - the introduction of a multi-dimensional decision framework that captures the risk-return angle and strategic considerations of the company at a divisional or enterprise level, addressing the need for stringent capital allocation as well as a vision to grow the company.

This chapter discusses each of these aspects in detail and the associated analysis that was conducted to build up the final decision-making framework.

6.1 Demand Forecast using Moving Average Analysis of Historical Sales

Forecasting is both a science and an art, and is necessarily a combination of realistic and aspirational expectations of the future. The current LTF process and outcome is more inclined to the latter, to the extent where most product groups lament that "our sales have always just hovered at this level, I do not understand why the forecast is up there". Additionally "the LTF fluctuates so much from one year to the next that it is difficult for us to make investment decisions". As discussed in Chapter 5, this feedback is, in large part, due to the positive and "recency" bias of LTF. I have therefore used the moving average technique to conduct a time series analysis and examined the forecasts that would be derived by historical trends alone. The hypothesis is that if forecasting by historical trend alone reveals a different and more stable trajectory, it would help reduce the general optimism or ambition in sales, and also tame the negative outlook when demand hits a trough.

Inputs to the model are the actual sales data for a specific product in the past 20 years, aggregated to establish an estimated level (Li) and trend represented by Cumulative Annual Growth Rate (Ri) for each year of forecasting. The model calibration requires 10 + 2 + 5 years of historical data. Assuming forecasting is conducted at Year i,

- Historical averaging period: the 10 years of demand (Y_{i-10} to Y_{i-1}) prior to the forecasting year *i* used to generate 3-year, 5-year and 10-year averages in order to capture both short-term and long-term trends
- The Sales and Operations Period (S&OP): Year *i* and Year *i+1* this falls under the S&OP period outside of the consideration for capacity determination
- The Forecasted Period: Year *i+2* to Year *i+6* are the actual years being forecasted based on the historical information. For calibration, we need to forecast the five years of EPP demand to find out optimal weights applied across 3-year, 5-year and 10-year averages such that the starting level and trend can be determined.

Detail calculations are delineated below:

Step 1: Assessing historical average levels and trends for demand projections

For forecasting conducted in year *i*, the corresponding EPP period is *i+2 to i+6*. In order to establish a level and trend for forecasting, we need to look back on the past N years (represented by t= i-N to i-1) of actual sales data:

N-year average level (L_i): $L_i = \frac{\sum_{t=i-N}^{t=i-1} Y_t}{N}$

N-year average trend (R_i): $\ln(Y_t) = \ln(b) + t \ln(R_i)$ for t = i-N to t=i-1, where ln(Ri) is the best-fit slope of the logarithmic curve using least square method using EXCEL's LOGEST function

where

$t = i\text{-}N$ *to* $i\text{-}1$ represents the backward looking period for determining level and trend

Y_t is the actual sales in year t

N is the number of years in consideration for the average

b is a constant in the logarithmic best-fit

While the average level is the simple mean of actual sales in the last three years, the average trend is calculated in two steps – first establishing a best-fit exponential trend line of last three years' sales, then assessing the cumulative annual growth rate of that trend line. This can be conveniently implemented using Microsoft EXCEL's built-in function of LOGEST. The level and trend then form the basis of predicting future demand.

It is recommended that the additional step of regression be undertaken versus the simple calculation of cumulative annual growth rate by using first year and last year actual sales, because the latter is prone to deviation considering the effect of cyclicality of the market. The formulae below summarize the calculations:

<u>Step 2: Optimizing weights to determine best ratio of 3-year, 5-year and 10-year averages to be used by minimizing forecasting error</u>

To establish the optimal weights applied toward the 3-year, 5-year and 10-year forecasts, the EXCEL add-in SOLVER is used to with an objective function of minimizing error across the forecasted period of 5 years (the duration of EPP) two years out from the forecasting year *i*, which is Year *i+2* to Year *i+6*. In this case, three different measures of error have been examined:

1) Mean squared error (MSE) = $\frac{\sum_{s=i+2}^{s=i+6}(Y'_S - Y_S)^2}{5}$

2) Mean percentage error (MPE) = $\frac{\sum_{s=i+2}^{s=i+6}\left(\frac{Y'_S - Y_S}{Y_S}\right)}{5}$

3) Theil's U statistic (U-stat): $U = \sqrt{\frac{\sum_{s=i+2}^{s=i+6}\left(\frac{Y'_S - Y_S}{Y_S}\right)^2}{\sum_{s=i+2}^{s=i+6}\left(\frac{Y_S - Y_{S-1}}{Y_{S-1}}\right)^2}}$

Where

s = *i+2 to i+6* is represents the forecasted period (EPP) carried out at year *i*

Y'_S is the forecasted value

Y_S is the actual value of a point for a given time period t

i is the year when forecasting is done

i+2 is the initial year of forecasted period

i+6 is the final year of forecasted period

N is the number of years in consideration (3, 5 or 10)

The optimization problem being solved is then:

Objective Function: Minimize (MSE or MPE or U-Stat) for forecasted period *i+2* to *i+6*

Decision variables: WL_3, WL_5, WL_{10}, WT_3, WT_5, WT_{10}

Constraints: WL_3, WL_5, WL_{10}, WT_3, WT_5, $WT_{10} \geq 0$

$WL_3, + WL_5,+ WL_{10}, = 10$

$WT_3, + WT_5,+ WT_{10} = 10$

where

WL_3, WL_5, WL_{10} are weights applied to the 3-year, 5-year and 10-year average demand levels, respectively, summing up to 10, and

WT_3, WT_5, WT_{10} are weights applied to the 3-year, 5-year and 10-year average trends, respectively, also summing up to 10.

The 3 error measurements are selected for their respective view emphasis:

- Mean Square Error – this method takes all errors into account and does not cancel out positive and negative errors, which is helpful in this case because it will otherwise difficult to recognize the actual error coming from actual data hovering around the mean (forecast trend line); it also places a greater penalty on large errors which is appropriate in this case as some level of error is expected albeit to only a limited extent; The absolute (and squared) nature of error makes it difficult to intuitive interpret the severity of deviation nonetheless;
- Mean Percentage Error – this method will allow cancellation of positive and negative errors, but also reveals more about bias in the forecast than accuracy of the error, which can be helpful in identifying the "recency" bias observed in the current forecasting process; by using percentage instead of the absolute value, it also gives a sense of severity of the error;
- Thiel's U-statistics – this method can be seen as dividing the Root Mean Square Error (RMSE) of the proposed forecasting method by that of the naïve method (merely guessing based on previous year's demand), thus assessing the strength of a formal forecasting method. It also emphasizes the importance of large errors like MSE does, but can be skewed by outliers (e.g. if the denominator approaches zero the U-statistics becomes much larger) and can be less intuitive and common than the above two measures.

While the outcomes for the three error measures are generally similar, for application in the EPP process it would be recommendable to use U-statistics as the main measure for two reasons:

(1) The penalty on large errors is in sync with definition of the forecast trend line – this is specifically relevant to the characteristics of the forecast being just a trend line through the mid-points (ideally) of demand. The actual is expected to hover about it, but error that is too large (and thus magnified in this case) is indicative of a less accurate forecast;

(2) The statistics demonstrates legitimacy of forecasting method and reflects on "recency" bias – U-statistics provides insight into how good the forecasting method is compared with the Naïve Method. This is in particular addressing the "recency" bias which reflects that current forecasting suffers a skew under the influence of actual sales data. Thus the U-statistic could help select a method that is superior to that in this cyclic industry where such influence is commonly observed.

The output of this model is a sequence of weights to the applied on short-term and long-term averages, which then determine the level and trend to generate the EPP forecast based on historical data. For most sample product groups, the optimal weights to be applied to the 3-year, 5-year and 10-year average are heavier on the longer-term and lighter on the short term. This indicates that reliance upon longer duration of averages produce a more stable trend line that better fits actual sales, and as such can mitigate the recency bias introduced by human psychology as actual sales fluctuate.

Juxtaposing moving average forecasts with actual sales and the LTFs as shown in Figure 6-1 and Figure 6-2, there are two observations made: (1) during Period 1, LTF seemed to be a better measure as it better represented the average trend line of sales being more balanced on both the overestimating (+ve percentage) and underestimating (-ve percentage) side, and was also fluctuating to a lesser extent; On the other hand, the moving average forecasts appeared to be leaning toward the optimistic side, and is fluctuating to a greater extent. This can be understood by the fact that historical sales in the ten years prior to Period 1 has gone through a faster growth than before; (2) during Period 2, however, the trends suggested by LTF are way above what is realistically possible looking back on history, given the combination of growth expectation in emerging countries and how soon global economy would recover; the moving average forecast suggests a more modest growth that may be possible despite the mining industry malaise.

The simulation seems to suggest that no single approach would be adequate to fully address the constraints in sales growth as reflected by historical figures, nor the global economics and industry dynamics which the LTF is trying to capture. With Caterpillar's aspiration to adopt a lead approach in its capacity planning (be asset-ready before demand signals come in) but also be value-generating for shareholders, a possible improvement to the current approach would be to incorporate both elements.

Figure 6-3 and Figure 6-4 show the forecast with a simple 50% weight applied to the two. It can be seen that the resulting forecast. For Period 1, we observe that (1) the growth in sales expected is much more reasonable; (2) the forecast still enables the meeting of peak demand; (3) the range of variation is moderated, thus the change in decision from year to year is less drastic. Looking at the forecasts in Period 2, a similar outcome is observed, that the forecast still carries the aspirational element of the LTF – that growth in the equipment sales can still be expected, but not to the extent where it would involve an investment way beyond what has historically demonstrated to be possible. A factor to remember is that according to the EPP procedures headroom of 25% is to be applied to this forecast. As such, it is ideal that the forecast is not overly aspirational in itself. This combined view with historical trend offers that taming effect.

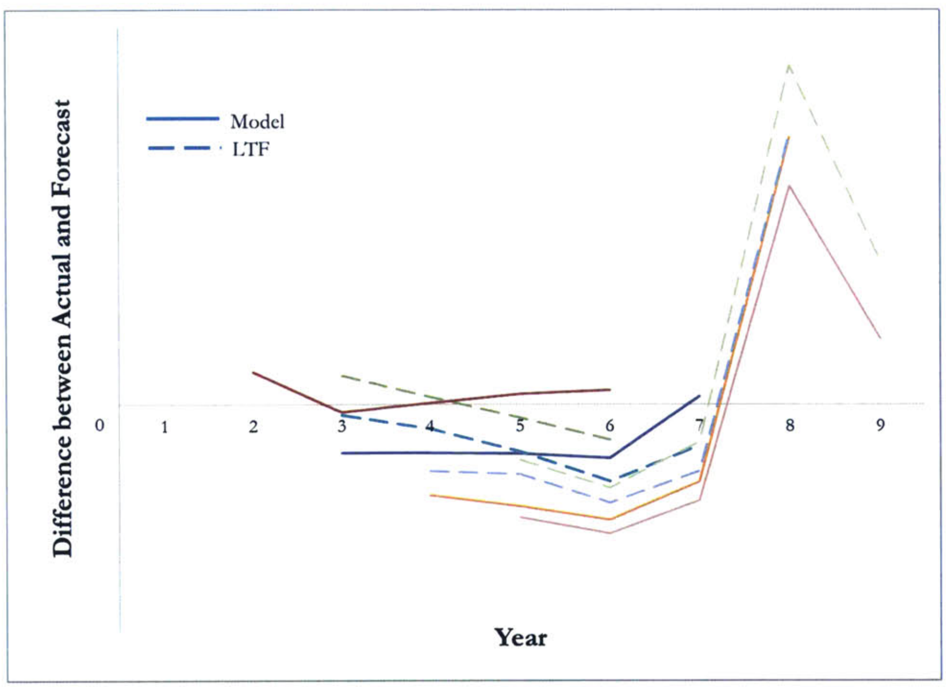

Figure 6-1 Difference between Actual Sales and Forecasting using proposed Weighted Moving Average Model and LTF for Period 1 (Product Group Y)

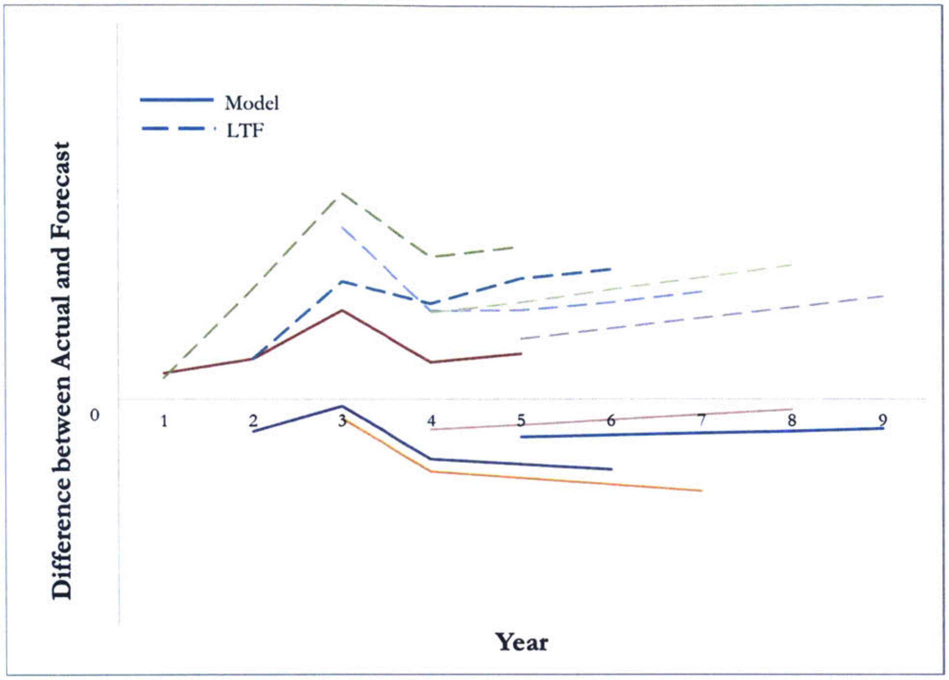

Figure 6-2 Difference between Actual Sales and Forecasting using proposed Weighted Moving Average Model and LTF for Period 2 (Product Group Y)

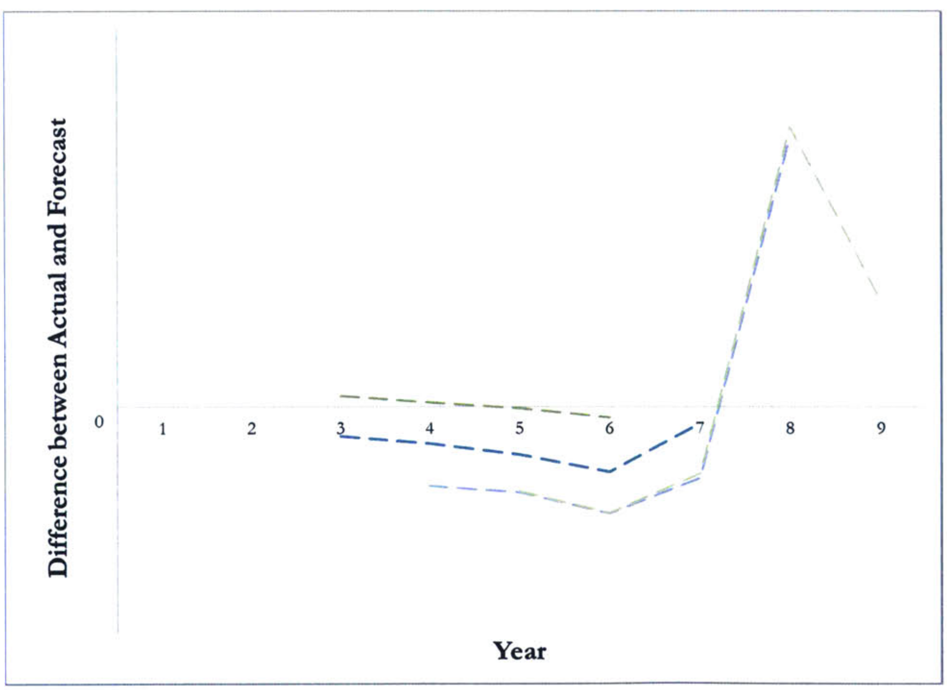

Figure 6-3 Difference between Actual Sales and Forecasting using Aggregated Forecasting for Period 1 (Product Group Y)

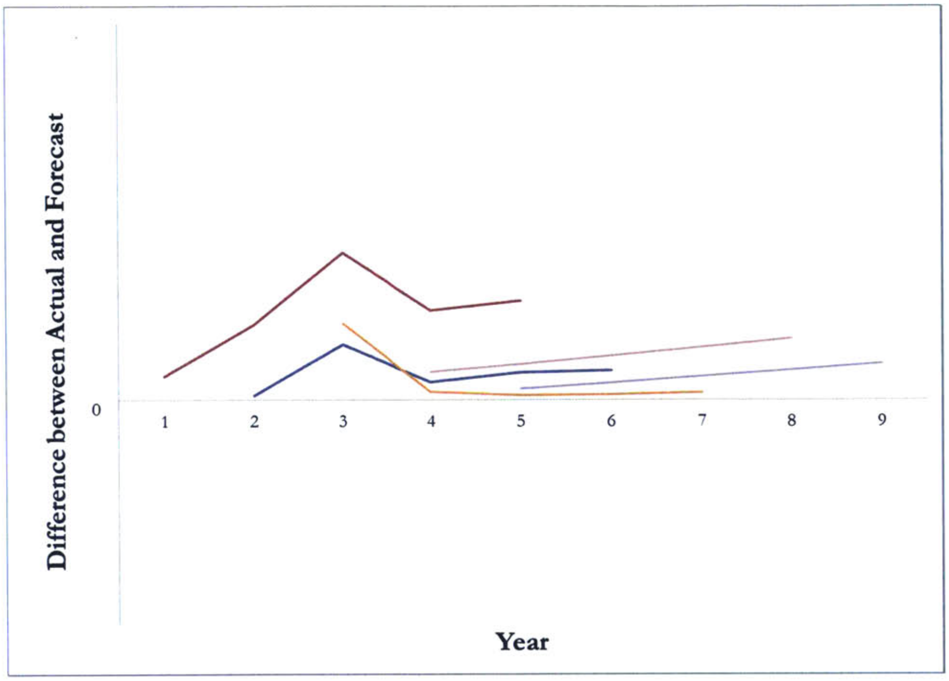

Figure 6-4 Difference between Actual Sales and Forecasting using Aggregated Forecasting for Period 2 (Product Group Y)

An example of such combined forecasting technique can be found in World Co. [26], a fashion company in Japan, which conducts their forecast using both a category (chain-wide forecasts for particular product categories based on projected chain-wide sales plans and product features) and a distribution (aggregate demand forecast for each store taking into account growth rates, changes in macro-economy, etc.) approach. The actual planning is based on larger of the two. In Caterpillar's case, this can be further optimized by using more detail data to establish the historical / aspirational ratio specific for each product group. It also depends on whether the product group has particular initiatives to support leaning more / less toward the aspirational forecast which makes deviating more from historical trends reasonable.

From a management perspective, this approach ameliorates the effect of "recency" bias by accounting for change in trends (indicated by increase/decrease in sales) in the historical analysis, while taming over-optimism in the long-term outlook. In addition, the disconnect between historical analysis and bottom-up LTF should also be reconciled between product groups and economists to understand source of variability and corresponding product strategy.

6.2 Financial Assessment of Project Options with Quantified Risk Measures

Given the uncertain nature of capacity projects, the risk exposure is as important as the return it is able to generate. With a risk-return perspective Product Managers can then make decisions in terms of the level of aggressiveness they desire for the product. To do that, an enhanced financial assessment approach is necessary to provide a quantitative view to the risk level involved, so that comparisons can be made and strategic measures taken to mitigate the risks. The deficiency in the existing "Sensitivity Analysis" approach is that it lends a view to the consequence of risks but not the probability. In order to attain the latter, a Monte Carlo Simulation of NPV analyses for a given project is developed, taking in all the input variability to generate a risk measure as an output.

The model has 5 key inputs:

1) Industry demand forecast: This is the LTF of the industry provided by Business Economics as a mid-point trend line with a percentage variability. In full implementation of the framework proposed by this thesis, this input will utilize the combination of historical data and LTF as illustrated in Section 6.1.1. The parameter is input as a normal distribution with the trend line as the average and the variability (which captures 90% of demand fluctuation) as 1.64 standard deviations away from the average.
2) Caterpillar Percentage of Industry Sales ("PINS"): There is a target PINS that product group would desire to achieve based on what the company has to offer in terms of product differentiation and marketing, as well as what competitive actions there are in the market. In an optimistic situation the product group may be able to achieve a higher PINS and vice versa. While it is unlikely that an unexpectedly high PINS would result, it is equally unlikely that it would be unexpectedly low as product groups would monitor the situation to adjust strategies accordingly. A TRIGEN model with maximum and minimum is therefore used to simulate the situation. This model allows the input of a triangular distribution, with maximum and minimum at a pre-determined percentile. Figure 6-5 illustrates the distribution.

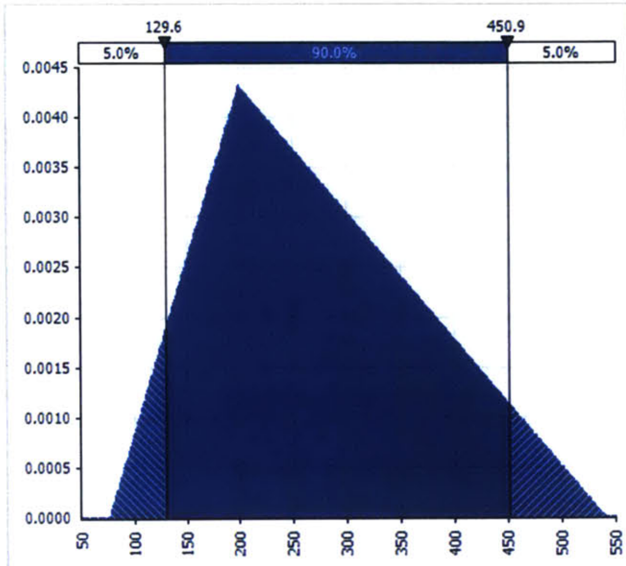

Figure 6-5 TRIGEN distribution

3) Prices: For each product there is a target price determined by the product group and the marketing team; to that discounts or mark-up are applied based on negotiations with the customers as well as market situation at the time. This requires participation from product group to determine the range of variation they would allow. Depending on which product(s) the capacity build is intended for, the inputs to average prices and range of fluctuation will also have to be amalgamated from individual model prices and an assessment of volume sales across the different models. For the sample runs, a TRIGEN model is used assuming there is a cap to which price is allowed to increase, and also a bottom where discounts are limited.
4) Costs: Similar to prices, each product has a per unit cost which is estimated from the historical data of fixed costs and variable costs given a certain volume. While fixed costs are unlikely to vary across product models, variable costs such as material cost would vary based on which models being produced by the new capacity are in higher demand. The amalgamation of data and estimates for inputs to average costs and ranges of fluctuation there have to be coordinated with product groups. For the sample runs, a TRIGEN model is used assuming there is a cap to which cost is allowed to increase, and also a bottom where cost reduction is limited.
5) Capital Expenditure: For each capacity build proposal the EPP team helps coordinate the compilation of timing and amount of expenditure required based on space and equipment provision specified by the product group. This forms the cash outflow requirement for the

project. A 10% fluctuation is allowed into the simulation under the TRIGEN model, as it is the project team's responsibility to limit that deviation.

With these inputs, the cash flow for each of the subsequent 10 years can be calculated to derive:

Average Internal Rate of Return (IRR) is the solution to

$$0 = -\text{ Capital Outlay} + \frac{CF_1}{(1+k)^1} + \frac{CF_2}{(1+k)^2} + \cdots + \frac{CF_n}{(1+k)^n}$$

and

Average Net Present Value (assuming a risk-neutral 12%) of the project

$$= -\text{ Capital Outlay} + \frac{CF_1}{(1+k)^1} + \frac{CF_2}{(1+k)^2} + \frac{CF_3}{(1+k)^3} + \ldots$$

Where

CF_i is the net cash flow in year i

k is the discount rate determined internally

Importantly, the simulation generates a distribution for these two measures which is indicative of the risk associated with the suggested return. Figures 6-6 and 6-7 show the NPV and IRR distribution curves of a sample project simulated with normalized data from a Green Book Proposal over the 10-year project life cycle, using 1000 iterations. The number of iterations required to reach a credible distribution depends on the degree of variability in the inputs. Given only 5 inputs are involved the relatively lower number of 1000 iterations was selected to limit run time.

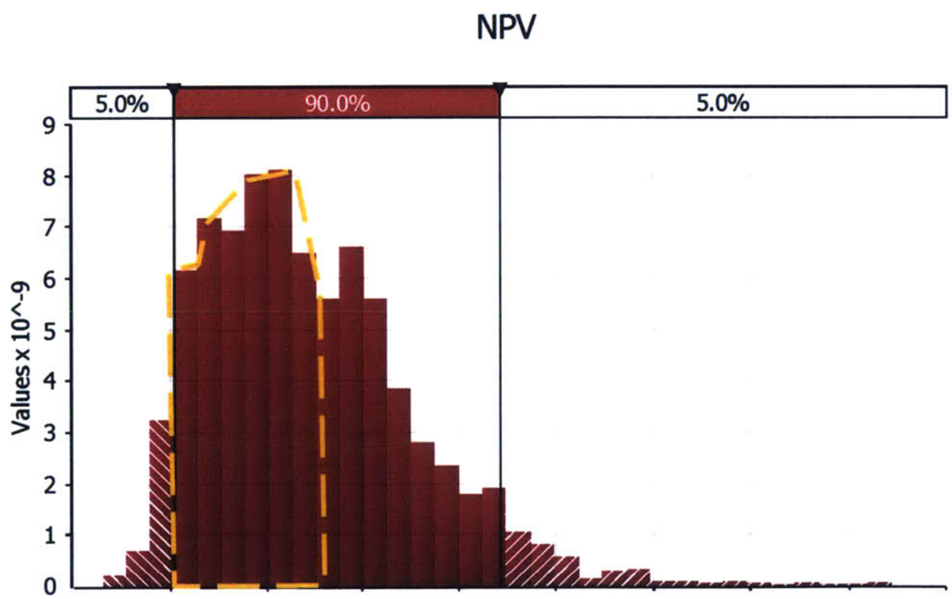

Figure 6-6 Probability Density Function of NPV from Monte Carlo Simulation

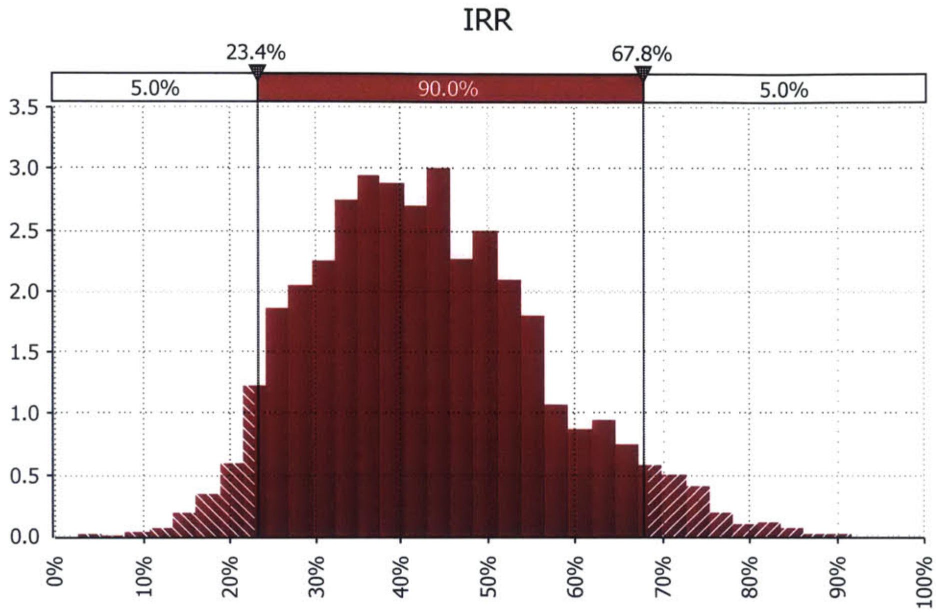

Figure 6-7 Probability Density Function of IRR from Monte Carlo Simulation

There are various risk measures that different industries use which has been described in Chapter 3. After discussion with Corporate Investment Governance and some product groups within the company, it is recommended that Value-at-Risk would be the best measure to serve the purpose of informing product group decision-making. The Value-at-Risk in this case, defined by the yellow dotted lines in Figure 6-6, is defined as the difference between the average NPV (at 12% discount rate not adjusted for risk because the distribution of outcomes is already taking into account the risks) and the 10th percentile NPV. This means that in addition to having a positive average NPV, the project is also not expected to lose more than that amount of present value with a 90% confidence given the risks involved. This is deemed to be an appropriate measure because:

- It is intuitive and easy to understand given its definition based on money terms;
- It reflects volume sensitivity (both industry / PINS) and more importantly the capital outlay – often times a key determining factor of project success as well as the only lever that can be pulled to curb loss when projects come short of their estimates;
- It is possible to compare this risk with other measures that matters to how much risk a product group or the company as a whole want to take – sales, risks of other projects, capital availability etc.

On the other hand, the main measure for return is proposed to be IRR – this provides a direct comparison with the cost of capital, which makes it easy to set a cut-off for project selection.

It also reflects a consciousness in capital spending, which echoes with the introduction of OPACC intended to focus more discipline around generating shareholder values.

What is not accounted for yet in the model is the interaction of variables. Understandably pricing strategy would influence PINS, and an increase in demand could lend pricing advantage to producers and vice versa. This can be incorporated in the next stage with more granular data and participation from different teams in the company to provide the necessary insights.

6.3 Holistic Decision Making Framework with a Strategic Lens

The Monte Carlo simulation detailed in Section 6.2 provides the objective view of risk and return which are common and important metrics for any investment. Nevertheless, with myriad investment opportunities available not all are equal even if they have the same risk and return level. There may be projects that are a strategic fit but not necessarily the most financially rewarding (lower return-risk ratio); there may also be projects that are lucrative but not in line with the company's strategy (easy money that is actually a distraction). A third dimension that a company should consider for its growth is the strategic fit – the alignment of a certain investment project with the long-term growth trajectory that the company is seeking.

To determine what goes into the consideration of Strategic Fit, 11 Green Book proposals were studied and the key factors for investment delineated in the narrative of the proposal were summarized in Table 6-1 Summary of Strategic Considerations in Green Book Proposals

	Support for Market Leading Product	Proximity to Significant Market	Enhancement of Vertical Integration	Sourcing / Production Flexibility	Competitive Response	Reduction of Cost, Lead-time and Waste	Strategic Partnership	Proximity to supplier
Project 1		X	X	X	X	X		X
Project 2	X	X	X			X		
Project 3	X	X				X		
Project 4	X	X		X		X		
Project 5	X	X			X			
Project 6	X	X				X		
Project 7	X			X	X	X	X	
Project 8		X						
Project 9	X	X						
Project 10	X	X						
Project 11		X	X	X		X		

.

The philosophy behind was discussed with Corporate Investment Governance as well as selected product groups to ensure legitimacy and practicality. From Table 6-1, three categories and five factors are selected to represent the strategic aspect that should be considered in capacity investment evaluation.

The selection on factors to consider is two-fold: firstly, it has to be significant enough, which is partially reflected by the tally in Table 6-1, but a more in-depth review of corporate strategy to understand the strategic implications of investment project would be prudent. Secondly, the factors should be mutually exclusive in themselves as well as with financial measures that are accounted for in previous sections. For this reason, the particular factor of "Reduction of cost, lead-time and waste" is not included here because it can be assessed and accounted for relatively easily.

Table 6-1 Summary of Strategic Considerations in Green Book Proposals

	Support for Market Leading Product	Proximity to Significant Market	Enhancement of Vertical Integration	Sourcing / Production Flexibility	Competitive Response	Reduction of Cost, Lead-time and Waste	Strategic Partnership	Proximity to supplier
Project 1		X	X	X	X	X		X
Project 2	X	X	X			X		
Project 3	X	X				X		
Project 4	X	X		X		X		
Project 5	X	X			X			
Project 6	X	X				X		
Project 7	X			X	X	X	X	
Project 8		X						
Project 9	X	X						
Project 10	X	X						
Project 11		X	X	X		X		

The selected factors are elaborated below.

1. Factors that improves alignment to long-term Global Production Network Planning (GPNP)
   - Sourcing / Production Flexibility Capacity build that moves the make/buy decision closer to the GPNP, and provides additional option and flexibility in sourcing or production, e.g. adding a second facility to minimize reliance on a single source
   - Proximity to significant market – Capacity build that creates presence in significant market, enables easy access for customers and reduces lead time to provide better services, e.g. moving manufacturing into the emerging market in Asia
   - Factors contributing to improving system robustness
2. Factors that improve product response to market
   - Support for Market Leading Products – Capacity build that supports signature products to protect company brand, competencies and development
   - Competitive response - Capacity build that overwhelms market, preempts new market entrants or prevents similar actions from competitors
3. Factors contributing to improving system robustness
   - Enhancement of Vertical Integration - Capacity build that enables better vertical integration, thereby enabling faster new product introduction, and in some cases innovation/system integration beyond what can be achieved with purchased components.

To give a unified and quantified value to the chart, a rating is to be generated for each of the sub-factors, which are then amalgamated into a final strategy score for the project. There are two ways to achieve that – a simple means would be to have senior management both from the product group and corporate functions to rate on individual attributes, the outcome of which is then used to provide an average (or a weighted average). Figure 6-8 Radar Chart for Assessing an Aggregate Strategic Value for a Capacity Projectis a radar chart illustrating the concept.

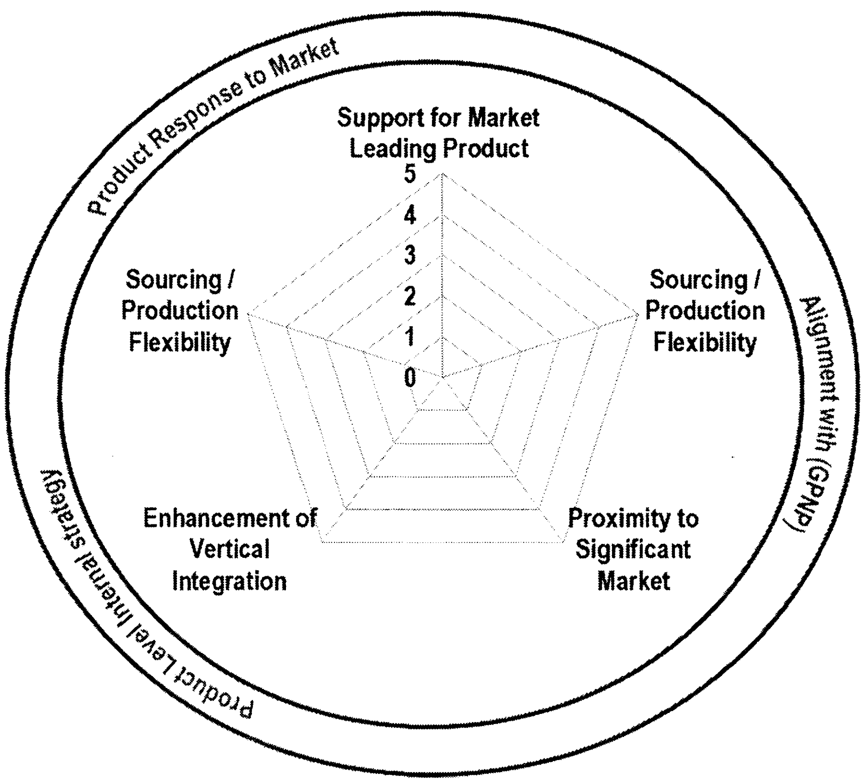

Figure 6-8 Radar Chart for Assessing an Aggregate Strategic Value for a Capacity Project

A second, more rigorous means would be to analyze the financial impact of each factor, benchmark it against some kind of baseline which can then be turned into a rating on a scale. The concept is similar to the reasoning for not considering "Reduction of cost, lead-time and waste" a strategic factor, but other metrics are more complicated to assess financially. An example can be the addition of a second facility which would add to production flexibility and reduce risk of stock-out or decreased capacity due to unforeseen situation with the single facility. The frequency of such occurrence and the magnitude of loss in each case then defines the extent of financial mitigation flexibility provides, and can then be incorporated into the return-risk analysis. Table 6-2 below summarizes the potential financial impact each strategic aspect has and how it can be measured or interpolated:

Table 6-2 Summary of Potential Financial Implications of Strategic Considerations

	Impact on Business	Impacts on Metrics	Verification / Incorporation into Financial Analysis
Flexibility / dual sourcing	- improves reliability of source and reduces recovery time in disruptions and improves services to customers	improve PINS	Historical data on financial implication of disruption due to single source in the form of PINS drop / Sales lost during recovery / Frequency of disruption
	- improves ease in recovery measures – contain cost variations during disruptions	reduces margin downside risk	
Enhancing vertical / horizontal integration	- improves reliability of source and reduces recovery time in disruptions and improves services to customers	improve PINS	Identification of areas of synergies and map to actual financial figures in terms of increased efficiency, reduced material, labor and machine cost
	- produces synergy (e.g. example of hydraulic mining shovel growth in Asia with ease in recovery measures - contain cost variations during disruptions	reduces margin downside risk	
	- enhances internal capability and innovation, increases speed of New Production Introduction	Improve PINS	New Product Introduction performance in more vertically integrated supply chains
Proximity to significant	- Reduces lead time, eases logistics, improves reliability of source and	improve PINS (and	Past measures on market share increase due to

market	reduces recovery time in disruptions	enhances aftermarket sales)	reduced lead time / increased presence
	- Increases market presence and improve brand image		
	- Increase participation in market		
Support Market Leading Products	- Build brand loyalty, prevent shift of customers to competitors	reduces prices downside risk (and enhances aftermarket sales)	PINS development upon capacity build and improved product availability; also historical deal-closing prices and previous price fluctuation and causes to identify correlation between market share and produce pricing
	- Build reputation	Maintain or improve PINS	
	- Preempts new entrants / protect against competitor taking PINS	Maintain or improve PINS	
Competitive Response	- Preempts new entrants / protect against competitor taking PINS	Maintain or improve PINS	Examine market share development upon capacity build and improved product availability;
	- Establish new markets where competitor already have a presence	Build PINS and introduce new sales	Profit increase due to increased sales (through PINS development)

A few points that should be noted for effective implementation of this approach:

(1) It requires in-depth study of historical values and trends for comparison, as well as that forecasted contribution of the proposed project. This may not be feasible within the short time-frame for putting together their EPP projections and potential capacity build plans, and should be discussed with product groups in detail to ensure accuracy and ease of obtaining such data.

(2) Some strategic goals are beyond the time frame for a specific project – for example, the entry into a significant market may be for a long-term, whereby the 10-year project being evaluated may not generate the entire return expected of the strategic move.

(3) There are aspects of strategic values that may not be solely captured by financial metrics alone, whether it is positive or negative. For instance, it is believed within Caterpillar that the strategy of vertical integration could bring about faster new product introduction and enable innovation that would not otherwise be possible with purchased component; some may, however, argue that it could stifle innovation and growth because of lack of external stimulation.

A case example is the study of autarkic corporations in the Northeast and network-based companies in the Silicon Valley [27]. Saxenian argued that independent firm-based system (similar to the concept of vertical integration) did not lend itself to the mutual learning and adjustments within the network which was critical to regional prosperity in the Silicon Valley, even though it might have offered for slower-changing industries some economy of scale and market control. The art of matching strategy with implementation is therefore not always captured by financial metrics in a single dimension.

As mentioned above, a deeper study of corporate strategy would be helpful to develop a more comprehensive matrix for assessment of strategic alignment. For example, capacity build that enables flexibility in the manufacturing processes (for multiple products) may not have a direct quantified benefit demonstrated in the financials, but can be significantly beneficial in managing demand troughs and workforces in such times. Caterpillar also has a target to win in China and other growth markets, as well as to develop a balanced portfolio across different industries – these are broader considerations that will not be fully reflected in the financial assessment of one project proposal.

6.4 Framework for making decisions on capacity investment projects

Section 6.1 delineates a more refined way of looking at demand forecast which enables the Monte Carlo simulation in Section 6.2 to provide an aspirational view to returns of projects while addressing spreads and risks that they have referencing historical patterns; Section 6.3 adds the additional factor of strategic value, which is reflective of the need for companies to be disciplined in terms of selecting projects that are relevant and not just lucrative.

Figure 6-9 juxtaposes these three dimensions of considerations and attempts to define where companies should invest. The ease with using this cube is that it set cut-off points for each dimension. By the assessment delineated in Sections 6.2 – 6.3, each project has a three-dimensional rating which places it in one of the zones in this cube, so that different stakeholders can establish consensus and focus only on "viable" projects for further examination. Inevitably the rating for strategic value will be most difficult to agree upon given it is not generated from a quantitative analysis.

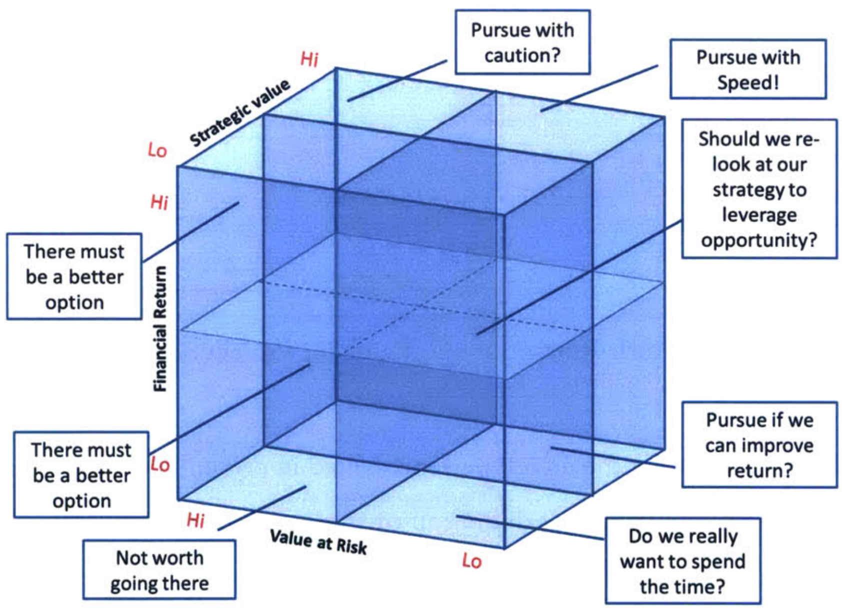

Figure 6-9 A Three-Dimensional Perspective to Project Evaluation

Where a hard cut-off may be difficult to determine, it is also informative to plot these three dimensions in the form of a bubble chart like Figure 6-10. To demonstrate the performance of this framework, Monte Carlo simulations of selected projects from business proposals have been conducted to generate the corresponding expected returns and values-at-risk. Strategic values of each project are assigned based on the narrative in the business proposal using the rubric defined by the radar chart (averaging the ratings across the five parameters). Each project is then plotted onto the bubble chart with x-axis being the value-at-risk, y-axis the expected return, and the bubble size the strategic value. The values that are represented here are from real data, but where granularity of information is needed assumptions have been made. As such, the plot in Figure 6-10 is for demonstrating the utility of the framework only.

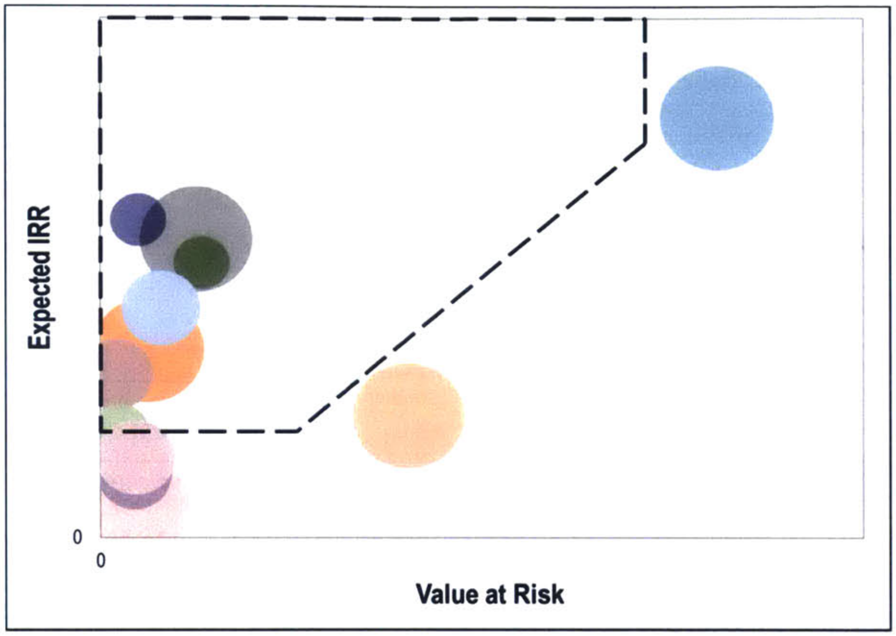

Figure 6-10 Return-Risk-Strategic Value for Project Selection

A critical input to this chart is the envelope represented in dotted line which defines the boundary for "viable" investment. The exact definition of this envelop is to be refined internally at Caterpillar by senior management, but to illustrate the intention of the chart this envelop is based on the following assumptions:

- There is a cost to the capital (expressed in percentage) which would be the minimum required return, and thus the lower bound of IRR for any investment project to ensure accretive value;
- There is a certain limit of capital risk to which a company should be subject, irrespective of what potential return a project can generate, and this forms the upper bound of Value-at-Risk;
- To obtain higher return one would inevitably have to accept higher risk, and thus there is a slope that defines the necessary rate of such risk-return relationship

Strategic values are, on the other hand, reflected by size of the bubble, so that management can exercise discretion when they make decisions on whether to proceed with more or less strategic projects. Using this framework, there is a more deliberate and quantified way to view strategy fit, and allow project evaluation at a division or enterprise level where different products are competing for resources.

Examining the plot in Figure 6-10, we can see that there are particular projects that promise very high return, but are also risking a significant sum of capital, potentially because of the important strategic move it represents; there are also projects where after post-investment review the returns were drastically returned in order to contain the risks, to the level where in hindsight they may not even pay for the cost of capital itself. However, it should also be noted that a lot of these projects have not completed their project cycles yet, and thus the data used here are still just estimates.

The proposed framework, from the demand forecasting to project selection, has a few implications:

- The combined forecasting technique engenders forecasters and product groups to reconcile differences in their outlook for a particular product, encouraging communication but also enabling more comprehensive consideration in forecasting future demands.
- A long-term view using the NPV approach for capacity decision is useful given the nature of investment, and its implication on corporate development. This measure mitigates the agency problem where the agent is incentivized to make decisions based on short term reward (given the metrics for performance assessment and tenure of product manager roles) and not the best interest of the principal.
- The impacts of an investment project on the company are multi-fold, and should be viewed in concert in order to position the company for both financial health and future development. A high risk project is not necessarily bad nor is a low return project. The decision to invest or not also evolves with time as the other performance metrics in the company vary (e.g. cash position, performance versus competition, shareholder demands) and thus the envelope for investment should be reviewed on a regular basis.

7 Conclusions

7.1 Recommendations

Capacity determination is a critical process for Caterpillar that affects the operations, the financials, and the direction of the company. The personnel and business units involved in the process are many, and thus the first step to understand the issue was to interview each stakeholder, from demand forecasting to actual investment decision making. Given the experience in 2008 when demand peaked and the company lacked capacity to 2013 when a challenging business climate created excess capacity, all stakeholders agree there could be more discipline around capacity investment decisions. The interviews revealed the perceived pain points in each part of the process.

i) From a process perspective

From demand forecasting to capital allocation, the project has looked into the chain of activities involved in capacity planning and made recommendation on what analysis and perspectives would enhance the process. The intention of such a process is to introduce more visibility into the different thinking across teams to spark dialogues (the comparison of historical trend and LTF), more clarity into the risk of investments in quantified terms for comparison (the three-dimensional comparison), and more understanding into how investments would necessarily take time to unfold and bear fruit (the long range perspective and variability incorporated in simulations). It is important to validate assumptions of the project as time goes by, but also to not let trends of the current year veil the broader picture of industry and company development.

ii) From an organization management perspective

It is not adequate to just have a process in place, because decisions are ultimately made by humans. Various researchers [28, 29] have studied the disconnect between financial consideration and strategic assessment, and suggested a formalized framework within the Agency Theory to reconcile the perspectives, ownership and control between the principal and the agents.

In this case the principal would be the long-term interest of the company, and the agents the product managers and other stakeholders involved in the capacity planning process. Understanding the interests of different stakeholders in the process and how they are incentivized and rewarded would be key to the success of any process. In this case, whether OPACC or PINS or other metrics is the best measure to monitor company health and staff/business unit performance is something to be reviewed. It can be seen from precedents that the drive for PINS can lead to over-aggressive capital investment to overwhelm the market with capacity. There is also the concern with one year of negative OPACC impacting product groups to make important decisions about capacity. There is the need to define company positioning and desirable behavior in its employees, and institute an appropriate system to measure and reward performance so that actions and decisions taken would be conducive to long-term benefits of the company.

7.2 Next Step

With initial consensus between the Caterpillar Production System and the Corporate Investment Governance team that the proposed framework is the direction to go, the next step would be to further engage product groups. Some of them have already been involved in the project and would be excellent pilot teams; some have not been consulted before and it would be important to understand if the proposed framework works well with their existing process. Additionally, data used in the system should be easily available or obtainable within the timing of EPP. This may require an exercise in data unification and data structure management. In any case, more in-depth analysis using granular historical data to enhance applicability of the solution in terms of the following:

- the determination of best ratios to be applied for individual product groups in setting the balance between historical trend and LTF;
- the analysis of historical data to glean more information on distributions to be used for input parameters, their correlations, as well as financial implication of strategic values;
- the expansion of the model to provide useful outcomes for both single product and multi-facility decisions; and
- the definition of an envelope for investment by management regarding the risk and return that could be taken by the company at a division or enterprise level, and how much do strategic values matter in this matrix.

7.3 Opportunity for Future Projects

While the above section made some suggestions on next steps to pursue in order to refine the proposed framework, there are also new directions that can be looked into to enhance the process or remove its constraints. These are in and of themselves a significant project that can be considered for future internships:

(1) Investigating Opportunity to Build Flexibility into Capacity – a large part of the constraint imposed on capacity planning is the lack of flexibility – this increases lead-time, limits expansion options, requires significant capital, and does not provide a solution when there is short-term trough demand that one must deal with. Re-examining how the factory floor should be set up, how different facilities can collaborate and how the operations / hardware can accommodate manufacturing of different products would help bring down the supply risk.

(2) Understanding the correlation of corporate strategy and supply chain strategy via focused study within Caterpillar with external case examples – in the ideal case supply chains are designed to reflect corporate strategy and goals; this is often difficult given the many physical constraints as well as softer relationships to be managed; there are also "myths" about what certain strategies can do for companies (e.g. emerging market entry, vertical integration, dual sourcing etc.) and it would be helpful to actual develop quantified cases around them.

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